Hot-Mix Asphalt Railway (Bituminous) Railway Trackbeds: In-Track Tests, Evaluations, and Performances – A Global Perspective

Professors of Civil Engineering
261 Raymond Building
University of Kentucky
Lexington, KY 40506

Dr. Jerry G. Rose, P.E.
jerry.rose@uky.edu

Dr. Reginald R. Souleyrette, P.E.
souleyrette@uky.edu

“When Rail Meets Soil” Technical Workshop
Caltrain Headquarters
San Carlos, CA
May 14, 2014
Classic All-Granular Trackbed

Typical Thickness (mm)

250-300
100-150
Asphalt Underlayment trackbed without granular subballast layer

Typical Thickness (mm)
300
150

Asphalt Combination trackbed containing both asphalt and subballast layers

Typical Thickness (mm)
300
150
100

Ballastless trackbed containing thickened asphalt and subballast layers
United States Applications

Since 1981

- **Short Maintenance**—Highway crossings, Turnouts, Rail Crossings, Tunnels, Bridge Approaches, WILDS, Open Track, etc.
- **Capacity Improvements**—Double Tracking, Line Changes, etc.
Strengthens Trackbed Support
Waterproofs Underlying Roadbed
Confines Ballast and Track

Dense-Graded Highway Base Mix
25 – 37 mm (1 – 1 ½ in.) Maximum Size Aggregate
Asphalt Binder +0.5% above Optimum (optional)
Low to Medium Modulus Mix, 1 - 3% Air Voids (optional)
BNSF Double-Tracking of Transcon: mid-1990s--mid-2000s
BNSF/UP Grade Separation in Wichita, KS, _______
SW Durham Rd.
May 15-16, 2010

Rail/Highway Crossing Maintenance/Rehabilitation
Rehabilitating/Lowering Tunnel Floors and Approaches
New and Rehabilitated Bridge Approaches
Renewing/Rehabilitating Turnouts and Rail Crossings
New and Rehabilitating WILDS
Trackbed Measurements & Evaluations

- Earth Pressure Cell
- Piezoelectric Film Sensor
- Track Deflection
- Track Stiffness
- Long-Term Track Settlement
- Trackbed Materials Tests
Pressure Cell

- Geokon Model 3500-2
- 9 in. Diameter
- Strain Gage
- Snap-Master
- Thermistor

Cell Placement on Asphalt
Empty Coal Train at Conway

P-Cell 209 on 5 in. HMA Layer

Pressure (psi) vs. Time (s)

- 4 6-Axle Locos
- Initial 5 Cars
Reduction of Dynamic Stresses*

*Source -- AAR Transportation Test Center – Pueblo, CO*
• Matrix-based array of force sensitive cells
• Silver conductive electrodes
• Pressure sensitive ink – Conductivity varies
• Crossing of ink – strain gauge

View of Tekscan Sensors

Tekscan Measurement Configuration
This represents a typical pressure distribution between a machined steel tie plate and the rail with an included rubber bladder.
Positioning of Lead Wheel with Respect to Sensor

Lead Wheel Position

Snapshot of the Lead Wheel Directly above the Sensor

Lead Wheel Over Sensor

F = 25372 lbf, P = 529 psi
Track Deflection Tests

Using LVDTs
Loaded Coal Train at Conway

5 in. HMA Layer on Wood Tie Track

Deflection (in.) vs. Time (s)

- 2 6-Axle Locos
- Initial 7 Cars
Test Results in Track Modulus and Subgrade Stress

---

### Track Modulus (lb/in./in.)

- **18 in. granular tracks**
- **4 in. HMA**
- **8 in. HMA**

### Subgrade Stress (psi)

- **18 in. granular tracks**
- **4 in. HMA**
- **8 in. HMA**
Long-Term Trackbed Settlement on Approaches and through Crossing

(20 Crossings in Study)
Representative Data for one Rail/Highway Crossing. Average Settlements through Crossings was 42% of Settlements on Approaches for the 20 Crossings.
Trackbed Materials Tests

Core Drilling
Subgrade Findings/Discussion

• In-situ Moisture Contents
  – Remain Consistent Over Time (1999—2008)
  – Compare Favorably With Optimum
• Assume Unsoaked, Optimum Condition for Design
• Bearing Capacities Remains At or Near Optimum
• Wide Range of Subgrades Evaluated
• Minimum Loading Induced Stresses on Subgrade.
Asphalt Findings/Discussions

• Resilient Modulus Values are Intermediate in Magnitude-Typical of Unweathered Asphalt Mixes
• Asphalt Binders do not Exhibit Excessive Hardening (Brittleness), Weathering, Deterioration or Cracking
• Asphalt is Insulated from Environmental Extremes
• Asphalt Experiences Minimal Loading Induced Stresses
• Conditions Influencing Typical Failure Modes Experienced by Asphalt Highway Pavements don’t Exist in Asphalt Railroad Trackbeds.
International Applications

Italy
France
Germany

Japan
Spain
Austria
Italy

Widely Utilized On Italian High-Speed Railways

• Rome-Florence: 252 km (1977-1986)
• Debated between cement and asphalt
• Asphalt – designated on all future high-speed passenger lines
- Prevents rainwater from infiltrating the layers below the embankment
- Eliminate high stress loads and failures of the embankment
- Protect the upper part of the embankment from freeze/thaw actions
- Gradually distribute static and dynamic stresses caused by trains
- Eliminate ballast fouling

Buonanno, 2000
Typical Cross Section

- 12 cm of asphalt with 200 MPa modulus
- 30 cm of super compacted subgrade with 80 MPa modulus
- 35 cm of ballast on top
Italian Trackbed Construction – Improved Subgrade on left, prior to addition of Granular and Asphalt Subballasts on right
• Increased safety and structural reliability due to increased modulus and uniformity
• Reduced life-cycle cost on the infrastructure from reduced subgrade fatigue
• Increased homogenization of the track bearing capacity on the longitudinal profile and better ballast confinement
• Reduced ballast fouling due to improved drainage
• Reduced vibration levels throughout the track therefore reducing noise
• Reduced thickness compared to a conventional granular design

Advantages of Bituminous Subballast

Teixeira, 2005
Italian Railways Bituminous Trackbed Construction

Compacting Subgrade and Placing/Compacting Asphalt

Spreading and Compacting Ballast
Falling Weight Deflectometer for assessing Structural Competency

Station View of Completed Asphalt Trackbed
Japan

- Widely Used
- High Speed/Regular
- Firm Support for Ballast
- Reduce Load Level on Subgrade
- Facilitate Drainage

Momoya and Sekine, 2007
New Railway Roadbed Design

Yoshitsugu MOMOYA
Assistant Senior Researcher, Track Structures and Geotechnology, Track Technology Division

When laying track on earth structures, roadbed performance is extremely important for controlling track settlement and dynamic deflection. In order to meet roadbed performance demands in Japan, concrete roadbed is used for slab track (Fig. 1), and asphalt roadbed is used for ballasted track (Fig. 2); this structure is also standard for the Shinkansen bullet train. The roadbed design methods are described in the “Design Standard for Railway Structures (Earth Structures).” In the January 2007 revision to this design standard, a performance based design method was introduced.

As the previous Design Standard for Railway Structures (Earth Structures) was based on specifications, the thickness of each layer of the roadbed design was specifically defined. With the performance based design method, however, it has become possible for the designers to design roadbed thickness to satisfy roadbed performance requirements. Specifically, by considering the fatigue life related to the number of trains, a method of designing thickness according to the importance of a particular section of track is described. Also, while the previous design concept was not consolidated with regard to a concrete roadbed for slab track or an asphalt roadbed for ballasted track, with this revision the roadbed design methods have been grouped together systematically.

With the new design standard, the earth structure performance rank for the relevant track is determined by the relative importance of the section of track and the track type. When designing the roadbed, a type of roadbed is selected to suit each of the various performance ranks. For performance rank I, concrete roadbed or asphalt roadbed for ballastless track is selected; for performance rank II, asphalt roadbed for ballasted track is used; and for performance rank III, crushed stone roadbed for ballasted track is selected. After the type of roadbed has been selected in this way, the roadbed structure design is carried out.

In the case of a concrete roadbed (Fig. 3), the following effects of train loads are checked for: displacement of the roadbed, breakage of the reinforced concrete base, fatigue damage, cracking, contraction, and thermal stresses. For asphalt roadbeds, the following effects of train loading are checked: displacement of the roadbed and fatigue damage of the asphalt mixture layer. In particular, in the case of an asphalt roadbed for ballasted track (Fig. 4), fatigue failure had not been considered in the previous design; however, this time a design method based on fatigue life has been introduced.

In this way, by systemizing roadbed design thinking to suit the design standard revision, and with the introduction of the performance-based design method, flexible design to suit the importance of the track section has now been made possible.
• **Performance Rank I**: Concrete roadbed or asphalt roadbed for ballastless track
  – Concrete base thickness = 190 mm or
    Asphalt base thickness = 150 mm
  – Stone base thickness = 150 mm

• **Performance Rank II**: Asphalt roadbed for ballasted track
  – Ballast thickness = 250-300 mm
  – Asphalt base thickness = 50 mm
  – Stone base thickness = 150-600 mm

• **Performance Rank III**: Crushed stone roadbed for ballasted track
Ballastless Cross Section

- Mainly used for viaducts and tunnels
- Proposed a low noise solid bed track on asphalt pavement

Asphalt 200 mm thick
Ballasted Cross Section

- Asphalt Thickness: 50 mm
- Well-Graded Crushed Stone Thickness: 15-60 cm
France

- Paris to Strasbourg high-speed line
- 3 km asphalt subballast
- 574 km/hr (357mph) (test)
Comparative Cross-Sectional Profiles

Figure 13. Traditional and Asphalt Cross Sections (Bitume Info, 2005)
Testing

• Conduct tests for 4 years (2007-2011)
• Temperature sensors continuously recording air temperature
• Pressure Sensors and Strain Gages checked twice a year
• Accelerometers
Comments Relative to French Asphalt Track Section

Reduces overall cross-sectional thickness by 36 cm
Reduces quantity of fill material by 5,000 cubic meters/kilometer
Pressures under asphalt layer are one-half of granular sections
Deflections of asphalt track are one-third of allowable
Sleeper acceleration is not affected
Less maintenance is required on asphalt track
Asphalt track performs well
Based on performance, several more sections are planned

Source: Bitume Info, 2005 & Robinette, 2013
Spain

Asphalt Trackbeds

- Madrid – Valladolid
- Barcelona – French Border
Figure 15. Bituminous subballast sections built on the high-speed line Madrid-Valladolid, section between Segovia and Valdestillas (left) and on the high-speed line Barcelona-French Border, section Sils-Riudellots (right). Source: Teixeira (2009).
Figure 16. Track design with bituminous sub-ballast for Spanish high-speed lines standards. Source: Teixeira et al. (2009)
Germany

- Utilize several alternatives to conventional ballast design
- German Getrac A1/A3 – ballastless slab consisting of asphalt
- Concrete ties are anchored to the asphalt
Figure 18. German Getrac A1 Cross Sectional Profile

Figure 19. Getrac A1 Cross Sectional Profile with Hydraulically Bound Layer
Figure 21. Paving with Asphalt

Figure 22. Installation of Concrete Ties

Figure 23. Finished Getrac A3 Track at Brandleite Tunnel
Austria
Reasons for Implementing Asphalt Layers

How to install an Asphalt Layer?

Targets of an Asphalt Layer

– to allow road vehicles running on the sub-layer during construction phase independently from weather and sub-soil situation
– clear separation of sub- and superstructure during the whole service life

Advantages

– drainage effect for raining water hindering it penetrating the substructure
– avoiding the pumping up of fines into the ballast
– delivering a certain amount of elasticity
– homogenising the stresses affecting the substructure
Long Term Experiences
Jauntal, Carinthia

Maintenance free asphalt layer since 1963
Austrian Railways Conclusions

Asphalt layers improve the quality of track in defining a clear and long lasting separation between superstructure and substructure. This separation results in less maintenance demands of track and (thus) longer service lives. These benefits must be paid by an additional investment of 10€/m² within the initial construction.

*Life cycle cost analyses show that it is worth to implement asphalt layers on heavy loaded lines (> 15,000 gt per day and track), as then the annual average track cost can be reduced by 3% to 5%.*

However, implementation of asphalt layers cannot be proposed for branch lines carrying small transport volumes. Asphalt Layers must be understood as an additional investment in quality, then it pays back its costs. It must not be implemented in order to reduce quality in sub-layers, by for example reducing the thickness of the frost-layers.
Austrian Railways Implementation

Consequently asphalt layers of 8 cm to 12 cm form a **standard element** for new high capacity and high speed lines in Austria.

Due to the long interruption of operation installing of asphalt layers are not proposed within track re-investment and maintenance operations.

**Picture a to c:** new Koralm link

**Picture d:** Schoberpass-line, built in 1991
Concluding Discussion

There is considerable interest presently by International Railway Industry to develop Innovative Trackbed Designs

The Incorporation of a layer of Asphalt (Bituminous) Pavement within the Track Structure is becoming a Common Practice for Domestic and International Railways

It is used for Newly Constructed High Speed Lines and for Maintenance/Rehabilitation of Existing Freight Lines

The Asphalt Layer augments or replaces a portion of the Traditional Granular Support Layer
Concluding Discussion (continued)

The Primary Documented Benefits of the Asphalt (Bituminous) Layer:

1. Provides additional load distributing capabilities
2. Decreases load–induced subgrade pressures
3. Increases confinement for ballast
4. Maintains consistently low subgrade moisture contents
5. Insures maintenance of specified track geometric properties
6. Potentially decreases subsequent expenditures for trackbed maintenance and component replacement costs
Closure

• Represents Current Practices

• Not All-Encompassing

• Typical Activities

Thank You for Your Attention
ANY QUESTIONS ???

Dr. Jerry G. Rose, P.E.
Professor of Civil Engineering
261 Raymond Building
University of Kentucky
Lexington, KY 40506

859-257-4278

Jerry.rose.uky.edu

www.engr.uky.edu/~jrose